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Research on heat-transfer characteristics of solar cells and heat exchanger combined system and its optimization

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Abstract

The study of solar heat exchanger is committed to enhancing the thermal efficiency of the existing system to achieve a result that little electricity is required and clean energy is applied to cool in summer and heat in winter. It makes full use of sunlight energy, through photovoltaic and solar thermal effects to produce heat and power generation at the same time. The gravity heat pipe is installed on the back surface of a solar panel, so that heat from the solar panel can be transferred to the house. Thus, the photovoltaic efficiency of the solar cell is obviously improved without changing its solar board structure.

Keywords: air-conditioner, gravity heat pipe, solar cell panel, refrigeration, heating, green resource

1. Introduction

With the improvement of living standards, human demand for energy is increasing day by day. But along with the price of the coal and demand on air pollution emission controls gradually increase, the cost of electricity has arisen. So the development of efficient, environmentally friendly and safe energy has great prospects [1, 2]. At present, there are two main ways to use solar energy, i.e., photovoltaic and solar thermal. Due to its high costs, PV is not well developed. Solar thermal is fairly popular in people's living by using solar water heater. However solar water heater only plays a small part for living energy supply. Furthermore, currently the solar cells of single crystal and polycrystalline silicon on the market have an

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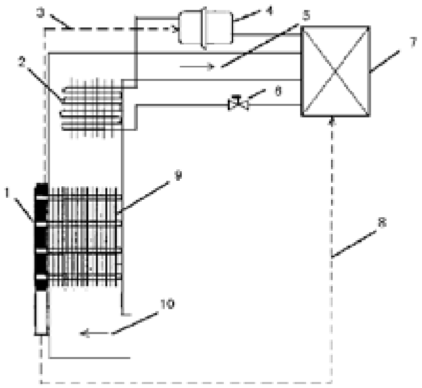
average efficiency of around 15%[3]. It is the main direction of solar energy economy to enhance the heat efficiency of heat exchanger.

2. The optimization of the existing units

The aim to optimize the existing system is to achieve a result that occupies little electricity, using clean energy to cool in summer and heat in winter. The system consists of the solar panels, heating pump, gravity heat pipe, indoor and outdoor heat exchanger. (Fig. 1)



1. Solar panels 2. Outdoor air heat exchanger 3. Power supply 4. Compressor 5. A warm air outlet
6. Expansion valve 7. Air heat exchanger 8. Power supply 9. Heat pipe and fin 10. Cold wind inlet
Fig. 1 The structure of solar air conditioning / heating system

The working principle of the system is that under normal working conditions of the solar cell, the heat of battery panel is taken away by the flow of the working fluid, which is water and water vapor, in the gravity heat pipe that is made of copper materials[4, 5]. In the wind tunnel, the heat is exchanged between pipe and fin by convection. Through the density difference between hot and cold air, the hot air is brought into indoor to heat the room. In summer, solar radiation are so abundant that electricity generated by the solar panels can drive heat pumps to accomplish endothermic cooling.

2.1. The system processing

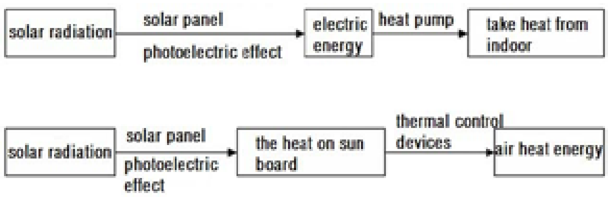
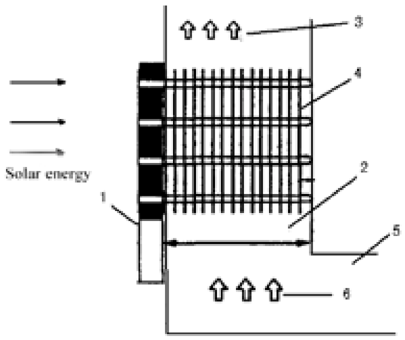


Fig. 2 The system processing

2.2. The heat exchanger composed of heat pipe and fin

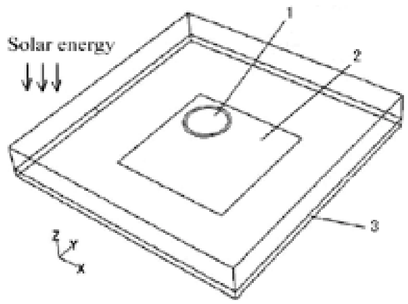
Heat pipe is a high efficient heat transfer element, which can transfer large amount of heat with a small area. The heat of the solar battery plate can be concentrated by the heat pipe through its one-way heat conduction. Gravity heat pipe without a capillary structure has the advantages of simple structure and convenient manufacturing process and liquid returns naturally to the evaporator by gravity, so the working fluid flow is stable and reliable. At the same time, it's flexible for piping arrangements. Compared with the capillary structure of heat pipe, it is easier to design and its cost is much lower. So it can adapt to most situations. However, the position of the condenser must be higher than the evaporation end. The schematic diagram of heat exchanger composed of heat pipes and fins is shown as Fig. 3.



1.Solar panel 2. Cooling section 3. Warm air 4. Fins 5. Hot air channel 6. The cold wind
Fig. 3 Schematic diagram of heat exchanger composed of heat pipes and fins

2.3. The connection between solar panels and heat pipes

The gravity heat pipe cooling mode is adopted in the system and water is the working substance. For the heat pipe, the design of evaporation end is an important part, which directly affects its ability to deal with the heat produced in solar concentrator photovoltaic cells and the ability to control its temperature. A good design of the evaporation end should ensure evaporation end transfer enough heat to make the operating temperature of the solar concentrator photovoltaic cell as low as possible, not exceeding the critical temperature, enabling it to continue working properly. The evaporation end of the heat pipe contacts the concentrator solar cells and its temperature field has an obvious effect on performance of the battery and efficiency of the heat pipe. In this chapter, the evaporation end is designed as a cuboid with the dimensions of length 100mm, width 100mm and height 30mm. The diagram of the heat pipe on solar evaporation end is shown as Fig. 4.



1.Gravity heat pipe 2. Layer of metal thermal conductivity 3. The back surface of solar panels
Fig. 4 The connection diagram of solar panels and heat pipes

2.4. Throttle switch

In summer, the air damper is put downward, which separates the vertical air channel from the horizontal air channel, letting the hot air directly emit into the atmosphere. While in the winter, the air damper is put upward, so the vertical and horizontal air channels are connected, letting the system heat the indoor room.

3. The theoretical analysis of experimental data on the solar energy air conditioning heating system

3.1. Case in the summer

The photoelectric conversion efficiency of solar panels on the market is 16% and it drops about 0.5% with each 1℃ rising of the temperature. In this chapter, TRM-PD artificial sun simulation emitter, whose light intensity ranges from 0 to 800 W/m^2, is adopted, from which the solar panels receive the simulation illumination.

The parameters of the equipment are as follows:

(a) The heat-absorbing plate: 1 mm of thickness copper plate, painted black to reduce the reflection to enhance absorption effect.

(b) The transparent cover: ordinary glass with dimension of 505 mm × 490 mm × 4 mm.

(c) The thermal insulation layer: glass silk with around 5 cm of thickness.

(d) The solar panels: its power is 20 W, working voltage is 17.6 V, working current is 1.14 A, open circuit voltage is 21.6 V, short circuit current is 1.33 A, with dimension of 426 mm ×406 mm ×30 mm.

The average values of the measured data of the solar panels are shown as Table 1.

Table 1 The average of the measured data during each flow period

Flux (L/min)	Inlet Temperature (℃)	Outlet temperature (℃)	Surface temperature of battery board (℃)	Atmospheric temperature (℃)	Voltage(V)	Current(A)
2.647	28.809	45.718	57.262	29.581	10.083	0.1246
3.103	29.155	50.780	59.591	30.258	10.088	0.1170
7.895	27.808	38.633	61.242	29.770	9.940	0.1216
15.000	28.012	34.551	62.582	30.506	9.962	0.1201
27.692	28.088	34.271	63.084	30.169	10.152	0.1176
36.000	28.049	31.356	62.128	30.409	10.076	0.1167

From Table 1 the average power P is:

$$P_{average} = \frac{\sum_{i=1}^{n} P_{Total\,i}}{n} = 17.18W \tag{1}$$

The output light intensity of solar energy simulator in the experimental system is 800W and the effective area of the solar energy panel is 400 mm × 300 mm, so the input power of panel is:

$$P_{inlet} = 96W \tag{2}$$

Without a cooling device, the solar energy utilization η1 is:

$$\eta_1 = \frac{P_{average}}{P_{inlet}} \times 100\% = 11.8\% \tag{3}$$

Adding the cooling device, the solar energy utilization η2 is：

$$\eta_2 = \frac{P_{average}}{P_{inlet}} \times 100\% = 17.8\% \tag{4}$$

It can be inferred that after adding the cooling device, the solar energy utilization rate is increased $\Delta\eta = \eta_2 - \eta_1 = 6\%$. Under this condition, if the solar panel area is 8m2, then the electric power output is

$$P = 558.66W \tag{5}$$

3.2. Cases in the winter

The winter condition is also designed according to performance parameters of the solar battery and the heat pipe installation model as mentioned above. It is assumed that the solar radiation intensity is 400 W/m^2, the average temperature of solar panels is 55℃, the average temperature of the heat pipe and fins is $t_f^{'} = 40^o C$, inlet temperature is $t_f^{'} = 10^o C$, heat length is 2.5m and air flow velocity is $u_m = 2m/s$.

Heat exchanging unit of this system is shown as Fig. 5.

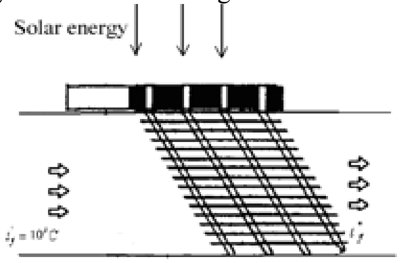


Fig. 5 Heat exchanging unit of this system

Assuming air temperature at the outlet $t_f^{''} = 25^o C$, then the qualitative temperature $t_f = (10+25)^o C/2 = 17.5^o C$, the corresponding physical parameters of air are $\lambda = 0.0276W/(m \cdot K)$, $\nu = 16.96 \times 10^{-6} m^2/s$, $\Pr_f = 0.699$, and $\eta_f = 19.1 \times 10^{-6} Pa \cdot s$.

It can be inferred that

$$\mathrm{Re}_f = \frac{ud}{\nu} = 11793 > 10^4 \tag{6}$$

The air flow in the turbulent field,

$$Nu_f = 0.023 \mathrm{Re}_f^{0.8} \Pr_f^{0.4} = 30.752 \tag{7}$$

$$h_f = Nu_f \frac{\lambda}{d} = 8.7W/(m^2 \cdot K) \tag{8}$$

According to the assumed exit temperature, the logarithmic mean temperature difference of air flow along the total tube length is equal to

$$\Delta t_m = \frac{t_f^{''} - t_f^{'}}{\ln[(t_f^{'} - t_w)/(t_f^{''} - t_w)]} = 22.46^o C \tag{9}$$

According to the surface heat transfer coefficient, the quantity of convective heat transfer can be calculated as

$$\Phi_1 = h_f 4lL\Delta t_m = 522W \tag{10}$$

According to the flow rate and the temperature rising from inlet to outlet, the total heat exchanging can be calculated as

$$\Phi_2 = q_m c_p (t_f^{''} - t_f^{'}) = 445.3W \tag{11}$$

The results of two total heat exchanging don't match with each other, because the assumed outlet temperature is not correct. Through the HRSolver computation to eliminate deviation, the result is:

$$h_f = 8.32W/(m^2 \cdot K),\ t_f^{''} = 22.4^o C,\ \Phi = 467W \tag{12}$$

Under winter heating condition, the reachable heat output of exchanger is 467 W.

4. After the optimization effect

From the above, a solar air conditioning/heating system has been developed in this chapter, and the efficiency of photovoltaic solar panel system increases 6% to 17.8% from the former 11.8% and output power of the simulated system in the experiment is 558.66w. In heat supply conditions in winter, the heat exchanger can output 467W of heat to the house.

5. Conclusion

It can accomplish the combination of heating in winter and cooling in summer and it can save energy and improve the efficiency of photovoltaic solar panels on the market. It provided a solution to low efficiency of solar cells and the heat exchanger combined system of solar energy photovoltaic battery. Calculate the summer and winter operating conditions through experimental simulation. The simulation results show that the energy storing efficiency of solar energy system was improved and it can effectively provide heat energy.

Acknowledgements

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